CDF
CMEX
UPGRADE

STRUCTURAL
AND
MECHANICAL
DESIGN

STABILITY
OF THE
FRAME

Stability of the Frame

As a general rule, structures are built with the intent to remain upright under most foreseeable situations. To insure stability, worst case situations of loading and movement should be reviewed and proven to still provide a stable foundation for the structure. Normally, a solid foundation with an adequately sized base would be used to support tall, slender, heavy, structures. However, when space constraints do not allow for this, it is necessary to find an alternate, but equally sound base for the support of the structure. This is the case with CMEX.

CMEX Upgrade is housed in the collision hall at CDF. There is little room to install large based structures which is why the CMEX stand is so narrow. Obviously, this poses a stability problem. It would appear that the structure would easily tip over. Two approaches were used to solve this problem.

Approach #1: **3" rise of C.G.**

A tall structure is generally more stable if the center of gravity (C.G.) is low. To help accomplish this, a large mass of steel is positioned at the base, on the base, and under the base to create the easiest and heaviest platform possible so that the C.G. would be as low as possible. Once the C.G. position of the entire structure is known (obtained from 3D solid modeler) and the base dimensions are known, a simple approach can be applied to determine stability.

A standard which has been used in the past is to allow the structure to tip about a pivot point until the C.G. has rotated to a position directly above the pivot point. At this position, any further rotation would cause the structure to topple. The vertical height, measured from the C.G. position at rest to the C.G. position after rotation, should be 3" or greater for the structure to be considered stable.

Approach #2: **Energy Method**

The energy method asks the simple question; at what speed will a rolling structure topple if its base is suddenly stopped.

Neglecting friction, an object traveling horizontally is losing or gaining no potential energy. In fact, all of its energy is kinetic and internal. Since internal energy of this object will remain unchanged, it may be omitted. When the object is abruptly stopped and begins to pivot about the base point, the kinetic energy decreases while the potential energy increases (due to the rise in C.G.). Like approach #1, when the C.G. is directly above the pivot point, it has reached its maximum height before it will topple. Assuming that it stops at this point and does not topple, all of its energy is now in the form of potential energy (we don't care what the energies were during rotation, only at the two extremes). This simply means that the kinetic energy before rotation must equal the potential energy after rotation; and surprisingly enough, it is not dependent on the weight of the object. The velocity required to accomplish this maximum rotation is:

$$V = SQRT\ (64.4 * h) \qquad \text{where h is the rise in C.G.}$$

Once velocity has been determined, it must be decided if it is possible to move the object at that speed. If it is possible, then stability will be questionable.

Calculations show that it takes 12-15 men to move the CMEX structure 4.22 ft/s (the critical speed for tipping) in a distance of 50 ft. This is absurd because there isn't 50ft of free rolling space in CDF and 12-15 men would be hard-pressed to gather let alone find room at the base to push without being in each other's way. Therefore, chain hoists will be utilized to perform a slow, controlled move of each CMEX frame.

An object, undergoing translation at a constant speed, that suddenly hits a stop, will pivot about that stop forcing a rise in C.G. (see diagram). The C.G. will rotate upwards with two possibilities: 1). C.G. rise small enough so as not to topple the object, 2). C.G. rise large enough to topple the object.

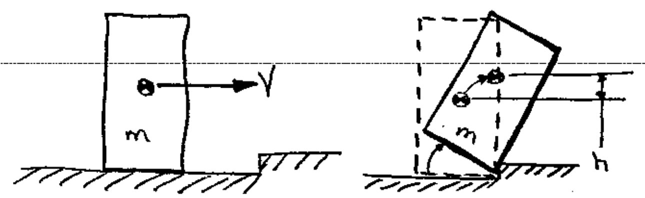
The critical point of rotation to maintain stability would be due to any C.G. rise that results in the C.G. being directly above the pivot point. Any further rotation would topple the object.

When the object hits a stop, pure translation stops, and rotation begins. This rotation causes the C.G. to rise; converting kinetic energy to potential energy.

Problem #1:

Assuming rotation stops when the C.G. is directly above the pivot point, what speed was the object traveling before the abrupt stop?

Solution by energy method:



When the object reaches its maximum height, during rotation, and then stops without toppling, it has converted all kinetic energy to potential energy plus frictional losses. (Neglect frictional losses).

$$T_1 + U_{1\to 2} = T_2$$

where T_1, T_2 equal initial and final values of kinetic energy

$U_{1\to 2}$ is the work of all forces acting on the rigid body

$T_2 = \emptyset$ because the rigid body is at rest at the final position.

$T_1 = \frac{1}{2} m V^2$

$U_{1\to 2}$ = potential energy gained when C.G. rises.

$U_{1\to 2} = mgh = wh$ where w = weight of object.

$$T_1 = -U_{1\to 2}$$

$$T_1 = -u_{1\to 2}$$

$$\frac{1}{2} mV^2 = -mgh$$

$$\left(\frac{1}{2}\right)\frac{w}{32.2} V^2 = -m(-32.2)h$$

$$\left(\frac{1}{2}\right)\frac{w}{32.2} V^2 = wh$$

$$\left(\frac{1}{2}\right)\left(\frac{1}{32.2}\right) V^2 = h$$

$$V = \sqrt{64.4\,h}$$

The C.G. must rise 3.32" to put the C.G. directly above the pivot point. 3.32" = .277'

$$\therefore \quad V = \sqrt{(64.4)(.277)}$$

$$\underline{V = 4.22 \text{ ft/sec}}$$

For a safely factor of "2", let h = 1.66" = .1383'

then $\underline{V = 2.98 \text{ ft/sec}}$

Problem #2:

Can a crew of workers push the frame to a speed of 4.22 ft/sec in a limited amount of space?

Solution:

"Hilman Rollers" suggest that it takes 35 lbs - 50 lbs per ton of force to overcome rolling friction. For a 30 ton frame this amounts to 1050 lbs – 1500 lbs of force.

An average man can apply 120 lbs of horizontal pushing force. Just to overcome the frictional forces, it would take between 9 and 13 men to push the frame.

Given a conservative 50 ft of free rolling space, the additional required force to obtain a toppling velocity of 4.22 ft/s is calculated as follows:

Equations of motion for constant acceleration

$$X = X_0 + V_0 t + \tfrac{1}{2} a t^2 \qquad V = V_0 + at$$

where
X = distance (ft)
V = velocity (ft/s)
t = time (s)
a = acceleration (ft/s²)

initial conditions are all zero.

$$50' = \emptyset + \emptyset t + \tfrac{1}{2} a t^2 \quad \text{and} \quad 4.22 \text{ ft/s} = \emptyset + at$$

$$50 = \tfrac{1}{2} a t^2$$

$$4.22 = at$$

$$100 = a t^2$$

$$\frac{100}{t} = at$$

$$\frac{100}{t} = 4.22$$

$$t = \frac{100}{4.22} = 23.7 \text{ sec.}$$

then, $a = .178 \text{ ft/s}^2$

$F = ma$ where $m = 1843.9$ slugs $\left(\frac{59375 \text{ lbs}}{32.2 \text{ ft/s}^2}\right)$

$$F = (1843.9)(.178 \text{ ft/s}^2)$$

$$F = 328.4 \text{ lbs}$$

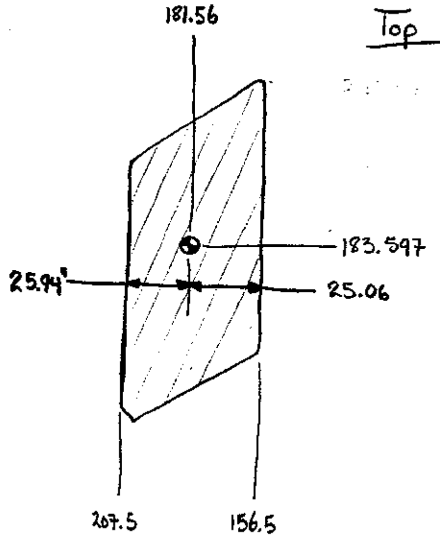
← That would require an additional 3 men to achieve this extra force.

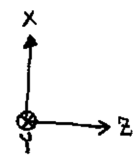
Conclusion:

It is absurd to use 12 - 15 men to move one CMEX frame.

Therefore, chain hoists with a slow, controlled pull ratio will be used for controlled, steady movement.

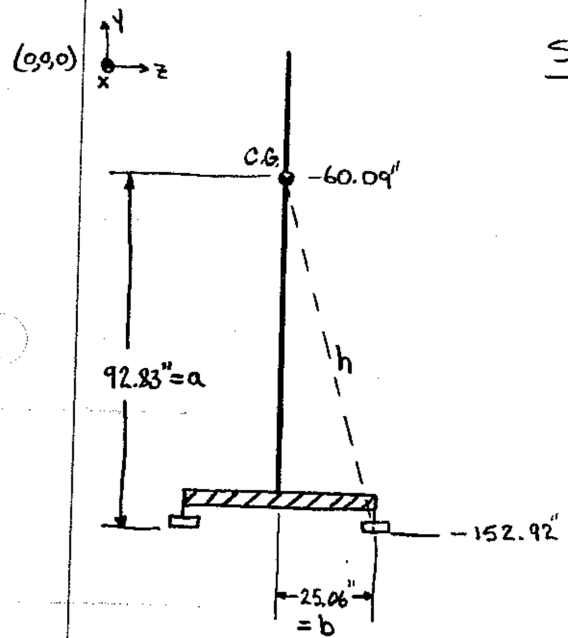
<u>Top View of Stand</u>

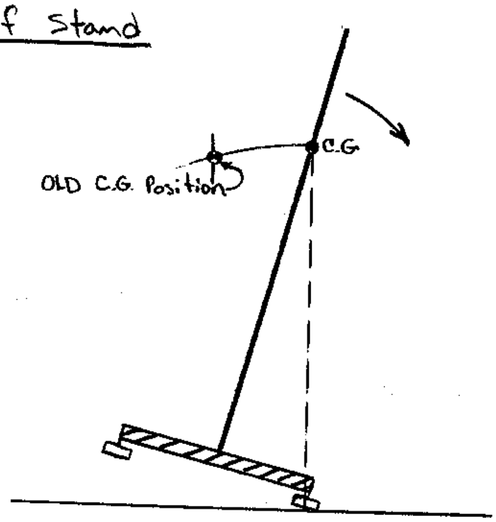


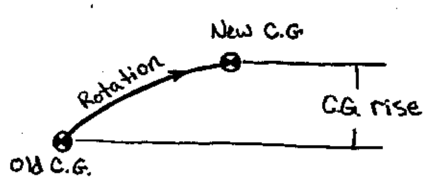


total weight = 59,375 lbs

<u>Side View of Stand</u>





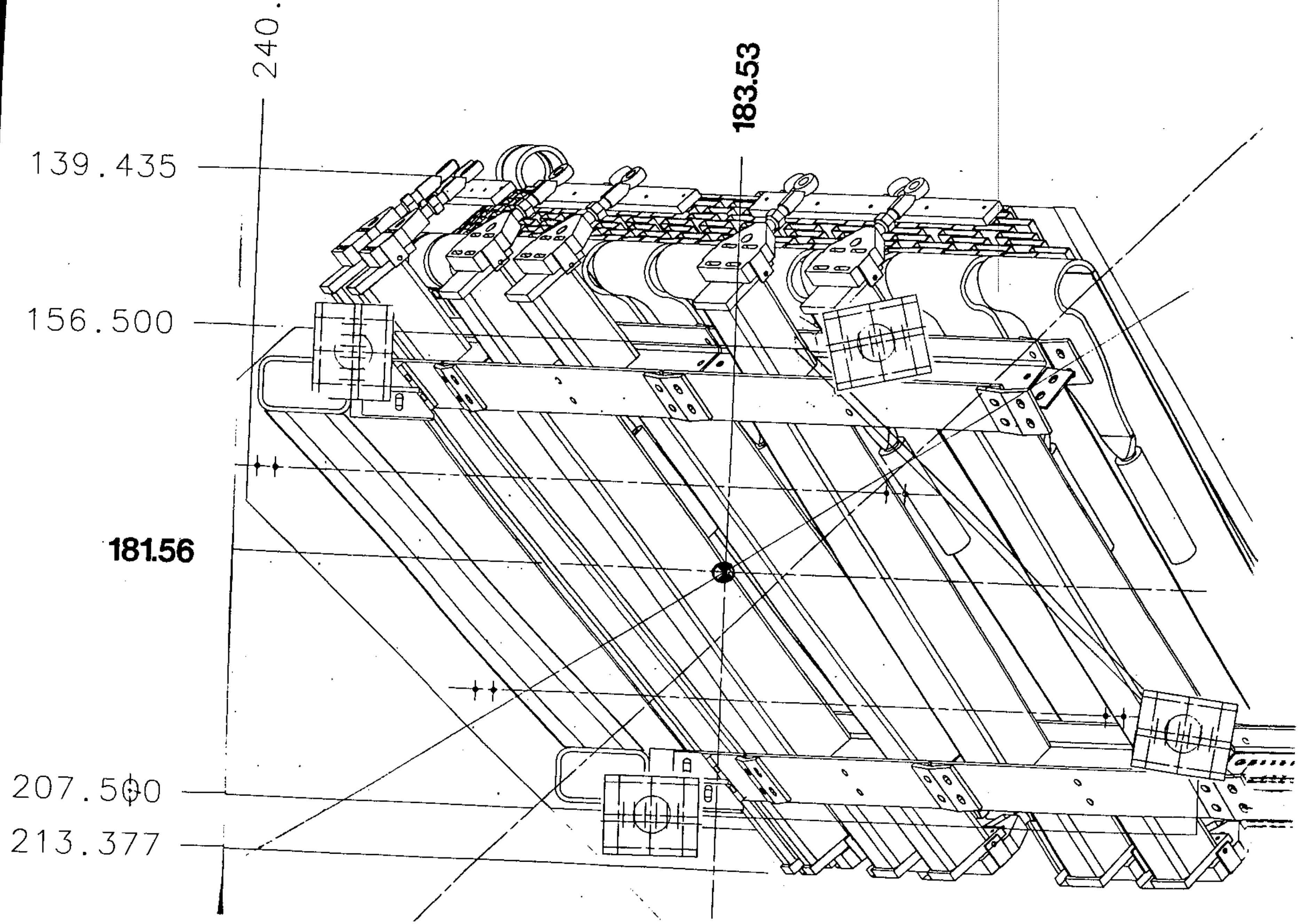


The rise in C.G. due to rotation about the base pivot point (Hilman Roller) should be 3" or greater for stability. The frame is rotated until the C.G. is directly above the pivot point. This is the point of maximum rotation allowed before tipping occurs.

The rise is calculated by: $h - a \geq 3"$

$h = \sqrt{a^2 + b^2}$ $\quad$ $h = \sqrt{92.83^2 + 25.06^2}$ $\quad$ $h = 96.15"$

$h - a = 96.15" - 92.83" = 3.32"$ OK



240.
183.53
139.435
156.500
181.56
207.500
213.377